DRAFT SF 298

1. Report Date (dd-mm-yy)	2. Report Type	3. Dates covered (from... to)

4. Title & subtitle	5a. Contract or Grant #
Shipboard Exposure Testing of Aircraft Materials Tri-Service Committee on Corrosion Proceedings	
	5b. Program Element #

6. Author(s)	
Edwin S. Tankins J. Kozol E. Lee	5c. Project # 5d. Task # 5e. Work Unit #

7. Performing Organization Name & Address	8. Performing Organization Report #

9. Sponsoring/Monitoring Agency Name & Address	10. Monitor Acronym
Tri-Service Committee on Corrosion USAF WRIGHT-PATTERSON Air Force Base, Ohio 45433	11. Monitor Report #

12. Distribution/Availability Statement
Approved for Public Release
Distribution Unlimited

13. Supplementary Notes

14. Abstract

15. Subject Terms
Tri-Service Conference on Corrosion

Security Classification of			19. Limitation of Abstract	20. # of Pages	21. Responsible Person (Name and Telephone #)
16. Report	17. Abstract	18. This Page			

TRI-SERVICE CONFERENCE ON CORROSION

21-23 JUNE 1994

SHERATON PLAZA HOTEL
ORLANDO, FLORIDA

PROCEEDINGS

Shipboard Exposure Testing of Aircraft Materials

Edwin S. Tankins*, J. Kozol & E. Lee

Abstract

A study was performed comparing the corrosion resistance of various aluminum alloys in shipboard environments with an accelerated laboratory corrosion test environment. An Al-Li access panel for the F/A-18 was also tested. For comparison 7075 aluminum alloys were tested in the exfoliation susceptible T651 and the resistant T7351 temper.

Sulfur dioxide salt fog (ASTM G 85 A4-85) tests were conducted. The shipboard exposures were performed aboard aircraft carriers deployed to the Pacific Ocean, Persian Gulf and Indian Ocean during the monsoon season. The Al-Li alloys exhibited pitting corrosion similar to 7075 T7351.

* Aerospace Materials Division, Naval Air Warfare Center Aircraft Division Warminster, PA. 18974-5000

Introduction

Considerable progress has been made recently in the development of new aluminum alloys and coatings for aerospace applications. The production of various aluminum-lithium alloys has made possible a density reduction and an increase in elastic modulus and strength. Over the last 20 years this Center has been testing many aerospace materials in marine environments as well as accelerated laboratory corrosion tests to compare the behavior of various alloys and coatings. The work presented here examines the corrosion behavior of a variety of aluminum alloys exposed to aircraft carrier environments. One of the in-house accelerated tests is also discussed for comparison to the carrier exposure. The high strength aluminum alloys are susceptible to various forms of corrosive attacks such as pitting, intergranular corrosion, stress corrosion, and exfoliation. Exfoliation is the most severe form of attack since it can destroy a structure. The objective of the entire program was to evaluate the behavior of various alloys on the decks of aircraft carriers as well as the effect of various locations in comparison to in-house accelerated tests. Although many different materials have been evaluated, the work presented concerns primarily aluminum alloys and various protective coatings.

Test Materials

A variety of materials has been evaluated including first and current generation Al-Li alloys. These include 2020 alloys from the 1950s used in the naval aircraft RA-5C, as well as present generation Al-Li alloys such as 2090 & 8090, and 1420 & 1421 produced in former Russia. The 2090 alloy was obtained through a Navy cooperative program and reported in Reference 1.

Commercially available 7075-T651 aluminum 1-in (2.54 cm) plate was used for comparison with the Al-Li alloys. After machining into step specimens, half of the specimens were overaged to the T7351 temper by heating for 24 hours at 120°C (350°F). There were a variety of the 7000 series aluminum alloys tested. The T6 and T7 conditions were similar to those shown in Table 1.
In the 7000 series, the high conductivity is characteristic of the T-7 condition.

Step specimens of a1 alloys were utilized to determine exfoliation corrosion behavior. The specimen dimensions were approximately 3 x 6 in (75 x 150 mm). The plate materials were machined to expose the surface at one-tenth (T/10) and one-half (T/2) of the plate thickness. The bare aluminum alloys were chemically etched to present uniform, consistent clean surfaces. The specimens were degreased with solvent, etched in 5% sodium hydroxide at 80°C (176°F) for 1 to 3 minutes, rinsed in water,

Table I - Plate Test Characteristic

Material	Plane	Thickness in	Thickness mm	Hardness Rb	Conductivity % Iacs[a]
7075-T651	T/0	1.0	25.4		
	T/10	0.90	22.9	91	32
	T/2	0.50	12.6	90	33.8
7075-T7351	T/0	1.0	25.4		
	T/10	0.90	22.9	81	39.9
	T/2	0.50	12.6	80	39.2
2020-T651	T/0	0.50	13.0		
	T/10	0.45	11.4	87	17.2
	T/2	0.15	6.5	89	17.2
8090-T851	T/0	1.80	45.7		
	T/10	1.64	41.6	77	19.8
	T/2	0.90	22.8	78	20.0

[a] Electrical Conductivity was measured in Percentage of International Anneal Copper Standard %(Iacs) unit

desmutted in concentrated nitric acid for 30 seconds, rinsed in deionized water and dried with oil free compressed air.

SO_2 Salt Fog -- The sulfur dioxide salt fog tests attempt to closely mirror the service environments. The model used in developing the tests was a high humidity, salt-containing environment. However, the acidifying species used are those found in service from jet-engine exhausts, i.e., sulfurous acid. The addition of a dry air purge accelerated, but did not change the corrosion behavior. Sulfur dioxide salt fog testing has been successfully applied to structural materials, organic coatings, and avionics (2).

Sulfur dioxide fog testing was performed in accordance with ASTM practice for salt/SO_2 spray (fog) testing ASTMG85A.4. (2) Testing was performed with 5% sodium chloride salt constant fog, with sulfur dioxide injection into the dispersion tower for one hour at six hour intervals. The nominal chamber temperature was 35°C (95°F): the step specimens were bottom supported at a 45° angle by acrylic racks. The testing campaign was performed for four weeks and for much lesser periods if the corrosion was severe. The Cd

plated 4130 steel was examined daily. The visual observations were recorded. The A1 step specimens were examined every other day except for holidays and weekends.

Table 2 shows a comparison of laboratory and carrier environments. These results are averages over long time spans (1-5).

Table 2 - Characteristics of Laboratory and Carrier Environments

ASTM	Conditions	Acidifying Agent	pH	Temp,°C	Relative Humidity,%
G85.A4	Continuous salt spray	SO_2	2.5-3.2	35	95
Shipboard	Cyclic salt spray	SO_X, NO_X, jet exhaust stack gases	2.4-4.0	23-29	71-87

Weather Reports

Weather reports were collected from hourly observations made by ship personnel (3). From these reports, data on temperature and relative humidity were taken four times daily at six hour intervals and analyzed. Conditions at the rack location may have differed from the meteorological data because of microclimate effects. For example, it is anecdotally reported that temperatures immediately above the black carrier deck can reach 140°F (60°C) during bright sunlight. Relative humidity was obtained by a procedure discussed elsewhere (4).

Aircraft Carrier Exposures

The study of various alloys included exposure aboard aircraft carriers as part of a series of exposures for the last ten years. Figure 1 summarizes the results of previous testing and shows that the carrier environment is more severe than seacoast or industrial environments (2). However, large differences exist between theaters of operations. Environmentally, the Indian Ocean deployment during the monsoon season is far more severe than the Atlantic or Mediterranean Sea deployment from which previous comparisons were made. Susceptible aluminum exposed aboard nuclear powered carriers (no stack gases)exhibited behavior similar to that aboard conventionally powered carriers (stack gases with jet engine

exhaust). It appears that the acidity of moist films measured on carriers is due primarily to exhausts from aircraft jet engines .

The exposure racks on which the specimens were mounted were on the flight decks. The racks were made of steel that had been cadmium plated, chromated, and painted. The specimens were insulated from the rack face by nylon washers and were fastened to the rack face with nylon bolts and nuts. Silicone sealant was applied in the bolt holes of the specimens and under the bolt heads to prevent crevice corrosion. The rack exposed the specimens at 45° to the horizontal. The steps of the specimens faced skyward. Single specimens of each material were exposed.

The racks were attached to radar towers from 1.8 to [illegible] m (6 to 12 ft) above the flight deck aft of the carrier island. Specimens in this study were exposed aboard two conventionally powered aircraft carriers. The *USS Constellation* was deployed to the Western Pacific and Indian Oceans for seven months (February through September), which included exposure during the monsoon season. The *USS John F. Kennedy* was deployed to the Mediterranean Sea for eight months. The *USS Nimitz* was deployed to the Western Pacific and Indian Ocean over a five year period. The *USS Ranger* was deployed to the Western Pacific and the Persian Gulf for 4 months. The various results have been published elsewhere (5-10).

Results and Discussions

There has been considerable testing performed in various locations. There are pronounced differences in locations and environments. For instance, the Indian Ocean during the monsoon appears to be more severe than the Atlantic or Pacific. The work of Ketcham. et al (2) showed a comparison of the various environments. Figure 1 was first shown in their work (2) and is an excellent comparison.

The macroscopic performance of the specimens after carrier exposure and laboratory testing was evaluated with the rating system of ASTMG34-87 (7). Thompson (7) discussed the procedure in detail. There are 8 by 10 in photographs that show the various rating systems. There are situations in which the corrosion cannot be compared to the ASTM standards. The results of recent tests are shown in Tables III and IV (8-10).

Aircraft Carrier Exposures

All shipboard exposed specimens were covered with a thin gray film. The analysis of similar films from previous exposures, indicated the film consisted largely of MIL-L-23699 engine oil deposits with some sulfur (2,5,7). The large

differences between similar specimens exposed aboard *USS Constellation* and *USS Kennedy* show a significant variation in corrosivity with deployment area (7).

The behavior of 2090-T8E41 and other Al-Li alloys exhibited pitting or very slight exfoliation. (7)

The shipboard exposures are from the *USS Nimitz* which was multiple deployment, the *USS Ranger,* which was a 4 month deployment, and a two year exposure in the Key West, Florida area (8-10).

Figure 2 shows a typical rack prior to deployment. The preparation of the rack as discussed elsewhere (8-10). Figure 3 compares a 7075-T6 step specimen with a T7 temper. This was a multiple deployment over a 5 year time period. The severe corrosion (ED) of the 7075 T6 can be seen. The T7 temper exhibits only general corrosion. The side view of the 7075 T6 is shown in Figure 4. The extensive exfoliation is readily available. Figure 5 compares a 7150-T651 alloy with a 2090 T8E41 alloy. The (E0) condition is readily apparent. The 2090 shows only general corrosion.

The results of the short time deployment of the *USS Ranger* is reported in table III. The results of the *USS Nimitz* multiple deployment is reported in table IV.

The results of the real time testing shows the T6 plate exhibits exfoliation on the T/2 plane. The T-76 temper demonstrated the improved exfoliation resistance of the overaged T76 condition. The remaining aluminum alloy control specimens in flat sheet configuration showed only some pitting and general corrosion. The Al-Li alloy step specimens showed only general corrosion and some pitting as reported in table IV.

After 2 years at Key West, Florida, a small amount of incipient exfoliation appeared on the T/2 plane of the 7075-T6. Figure 6a compares access panels of 7075T6 and 209078 Al-Li alloy for the F/A-18. Figure 6b shows what looks like a slight blistering at the scribe mark. By comparison Fig 6b looks clean at the scribe marks. The behavior is basically comparable.

The laboratory tests indicate at 96 hours the 0.3 mil and 0.5 mil Cd plated plate shows corrosion, and the 1 mil shows discoloration. These results are shown in Figure 7. This is similar to what is often seen on carrier exposure.

Laboratory tests of 7075 T7 sheet shows general corrosion or pitting within 1-2 days. The 7075 T6 sheet shows delineation of the grain boundaries but no exfoliation. 7075 T6 step specimens in previous tests showed exfoliation on the T/2 plane (7) after 700 hours of exposure. It appears that SO_2-salt fog testing is a relatively good simulation for the type of behavior of the aircraft material except the time involved is much shorter and the acceleration time varies with the material.

Conclusion

1. Shipboard exposure corrosion testing provides a real time test method for evaluating and ranking Naval aircraft materials and coatings.
2. The improved exfoliation resistance of 7075 T7 (overaged) aluminum alloy over fully aged 7075 T6 was demonstrated, even after a relatively mild exposure.
3. The general and pitting corrosion behavior of the aluminum lithium alloys (2090, 8090, and 1420, etc.), was comparable to that of the 7075-T7.

Acknowledgments

Funding for this program was provided by the 612 Aircraft Materials Block (NA2A). The authors wish to acknowledge Mr. Lee Biggs. Dr. Bart Boody, and Dr. John Deluccia for their assistance in evaluating the specimens after exposure testing.

References

(1) Bucci, R.J., Malcolm, R.C., Colvin, E.L., Murtha, S.J., and James, R.S., "Cooperative Test Program for the Evaluation of Engineering Properties of Al-Li Alloy e2090-T8X Sheet, Plate, and Extrusion Products," Report No. NSWC TR 89-106, Naval Surface Warfare Center, Silver Spring, MD, 15 Sept. 1989.

(2) Ketcham, S.J. and Jankowsky, E.J., "Developing an Accelerated Test: Problems and Pitfalls", *Laboratory Corrosion Tests and Standards, ASTM STP 866,* G.S. Haynes and R. Baboian, Eds., American Society for Testing and Materials Philadelphia, PA, 1985, pp. 14-23.

(3) "Manual for Ship Reporting of Surface Observations from a Sea Station", NAVOCEANCOMINST 3144.1C, 22 March 1983.

(4) Haynie, F.H., "Evaluation of the Effects of Microclimate Differences on Corrosion", *Atmospheric Corrosion of Metals, ASTM STP 767,* S.W. Dean, Jr., and E.C. Rhea, Eds., American Society for Testing and Materials, Philadelphia, PA, 1982, pp. 286-308.

(5) Jankowsky, E.J., Ketcham, S.J., and Agarwala, V.S., "Aircraft Carrier Exposure of Aluminum Alloys," Report No. NADC-79251-60, Naval Air Development Center, Warminster, PA, 1 Nov 79.

(6) Joseph Kozol and Edwin Tankins, "Aircraft Carrier Exposure Tests of Cast Magnesium Alloys", NAWCADWAR-93015-60, March, 1993.

(7) J.J.Thompson, "Shipboard Exposure Testing of Aircraft Materiel, Aboard USS Constellation (Feb-Sept. 1985)", NADC-87125-60, Sept. 1987.

(8) Joseph Kozol, E. Tankins & E. Lee, "Shipboard Exposure Testing of Aircraft Material Aboard USS Ranger", NAWCADWAR 94019-60, May, 1994.

(9) J. Kozol, E. Tankins, & E. Lee, "Shipboard Exposure Testing of Aircraft Material Aboard the USS Nimitz", Unpublished Data.

(10) J. Kozol, E. Tankins, & E. Lee, "Shipboard Exposure Testing Over A 2 Year Duration, Key West, Florida", Unpublished Data.

TABLE III. SPECIMEN DESCRIPTION AND OBSERVATIONS (Continued)

	Material Description	Designation	Configuration	Observation
17.	High Strength Aluminum Alloy	CW67T7	Sheet	General discoloration, no exfoliation, general corrosion.
18.	Silane Coated Aluminum Alloy	2024 Coated	Plate	General corrosion, some pitting and surface discoloration.
19.	High Temperature Aluminum Alloy	CZ 42	Sheet	General corrosion, some pitting and surface discoloration.
20.	Melt spun Al-Li-Zr Alloy	644	Forged, extruded step specimen	General corrosion, some pitting and surface discoloration, exfoliation appears to be just starting at T/2.
21.	Aluminum Alloy	Control, 6061T6	Plate	General corrosion, and some pitting.
22.	Aluminum Alloy	Control, 2024T6	Plate	General corrosion, and some pitting.
23.	Aluminum Alloy	Control, 7075T76	Step specimen	Pitting and general corrosion.
24.	Aluminum Alloy	Control, 7075T6	Step specimen	Exfoliation starting on mid plane. No evidence on top plane.
25.	Chromate Corrosion Coating, Unicoat Variation	2024T3	Plate	Blisters at scribe marks. Paint Surface looks good.
26.	Chromate Corrosion Coating, Unicoat Variation	2024T3	Plate	Blisters at scribe marks. Paint Surface looks good.
27.	Non-Chromate Corrosion Coating, Unicoat Paint	2024T3	Plate	No corrosion, some surface darkening.
28.	Non-Chromate Corrosion Coating, Unicoat Paint	7075T6	Plate	No corrosion, some surface darkening.
29.	Non-Chromate Corrosion Coating, Unicoat Paint	6061T6	Plate	No corrosion, some surface darkening, blisters may be forming.
30.	Alodine, Unicoat Paint	2024T3	Plate	Blisters may be forming.

TABLE III. SPECIMEN DESCRIPTION AND OBSERVATIONS

	Material Description	Designation	Configuration	Observation
1.	High Temp. Al alloy (Al-Fe-V-Si)	FVS 0812	Sheet	General corrosion, slight pitting not deep, slight surface discoloration.
2.	High Temp. Al alloy (Al-Fe-V-Si)	FVS 1212	Sheet	General corrosion, slight pitting not deep, slight surface discoloration.
3.	Aluminum Alloy	Control, 7075-T6	Sheet	Slight pitting not deep,and some general corrosion.
4.	Sealed Magnesium Alloy	WE-43		* Pitting of Al fitting, no galvanic corrosion discernible.
5.	Sealed Magnesium Alloy	QE-22		* No pitting, looks good.
6..	Unsealed Magnesium Alloy	QE-22		* Pitting of Al fitting with obvious galvanic corrosion at base of fastener.
7.	Cadmium Plated Steel (1 mil)	Control	Plate	Surface darkening, very slight general corrosion.
8.	Cadmium Plated Steel (0.5 mil)	Control	Plate	Surface darkening with edge corrosion.
9.	Cadmium Plated Steel (0.3 mil)	Control	Plate	Severe surface rusting.
10.	Aluminum Metal Matrix Composite	2124 T6, 15 vol SiC	Plate	Small amount of pi ng, general corrosion and some surface discoloration.
11.	Aluminum Alloy	Control, 7075 T7351	Plate	Small amount of pitting, general corrosion and some surface discoloration.
12.	Al–Li Alloy (Russian)	1421	Welded sheet	Pitting and general corrosion.
13.	High Strength Aluminum Alloy	CW67T7	Plate	Small amount of pitting, some surface discoloration, mostly general corrosion.
14.	Aluminium-Lithium Alloy	2090T8	Step specimen	General discoloration, no exfoliation, general corrosion.
15.	High Strength Aluminum Alloy	CW67 T6	Plate	General discoloration, no exfoliation, general corrosion.
16.	Molybdate, Silane Coated Aluminum Alloy	2024 Coated	Plate	General discoloration, no exfoliation, general corrosion.

TABLE III. SPECIMEN DESCRIPTION AND OBSERVATIONS (Continued)

	Material Description	Designation	Configuration	Observation
31.	Alodine, Unicoat Paint	7075T76	Plate	No corrosion, some surface darkening.
32.	Alodine, Unicoat Paint	6061T6	Plate	No corrosion, some surface darkening.
33.	Aramid Aluminum Laminate	Arall 5/4	Unsealed edges	General Corrosion - No discernible increase at laminated edges.
34.	Aramid Aluminum Laminate	Arall 5/4	Sealed edges	General Corrosion.
35.	Al-Li Alloy (Russian)	1420	Step specimen	Incipient exfoliation on both faces.
36.	Al-Li Mechanically Alloyed	Inco 905XL	Forging Step Specimen	No exfoliation, some pitting and general corrosion.
37.	High Strength Aluminum Alloy	CW67T7X1	Forging	Some pitting and general corrosion.
38.	Aluminum Metal Matrix Composite	2124 T6, 15 vol SiC	Sheet	Some pitting and general corrosion.
39.	High Temp. Aluminum Alloy	Al-12.6Mn, 4.8Si, 0.2 Fe	Extrusion	General corrosion, similar to #1 except darker discoloration.
40.	High Temp. Al Alloy (Al-Fe-V-Si)	FVS 1212	Extrusion	General corrosion, some pitting and surface discoloration.
41.	Unsealed Magnesium Alloy	QE-22		* Pitting of Al fitting, galvanic corrosion; coating at scribe in base material severely corroded.
42.	Sealed Magnesium Alloy	QE-22		* Severe corrosion at scribe, not as bad as #41.
43.	Sealed Magnesium Alloy	WE-43		* Tiny amount of corrosion at scribe, no galvanic effects noted.
44.	Al-Li-Mg Alloy (Russian)	1420w	Sheet	General corrosion, some surface discoloration.
45	High Temp Al Alloy (Al-Fe-V-Si)	FVS 0812	Sheet	Incipient pits, slightly more general corrosion than #1.
46.	Al-Li-Mg Alloy (Russian)	1421w	Sheet	Some pits, general corrosion.

Table IV Exfoliation Rating of Aluminum Alloys
Exposed on the USS Nimitz 5 Year Span

Material	Thickness	Plane	Rating
7075-T651 Plate	1 in (2.5 cm)	T/10	EA
		T/2	ED
7075-T43 Plate	"	T/10	EA
		T/2	EA
7075 RRA Plate	"	T/10	EA
		T/2	EA
7150-T651 Plate	0.5 in (0.6 cm)	T/2	ED
7150 T7E95	"	T/2	Pitting(<EA)
7150 T7651	"	T/2	Pitting(<EA)
2020 T651	1 in (2.5 cm)	T/10	Pitting(<EA
		T/2	Pitting(<EA
2090 T8E41 Plate	0.5 in (1.2 cm)	T/10	Pitting(<EA
		T/2	" "
8090 T8 Plate	2 in (5.08cm)	T/10	Pitting(<EA
		T/2	" "
CW67 Plate	0.25 in (0.6 cm)	T/10	Pitting(<EA
CW67 Plate	1 in (2.54 cm)	T/2	Pitting(<EA
CW78 Plate	0.5 in (1.2 cm)	T/2	" "
7064 B1 Plate	0.5 in (1.2 cm)	T/10	" "
		T/2	" "
2519 (Plate)	0.5 in (1.2 cm)	T/2	Pitting(<EA
2519 (Plate)	" "	T/10	" "

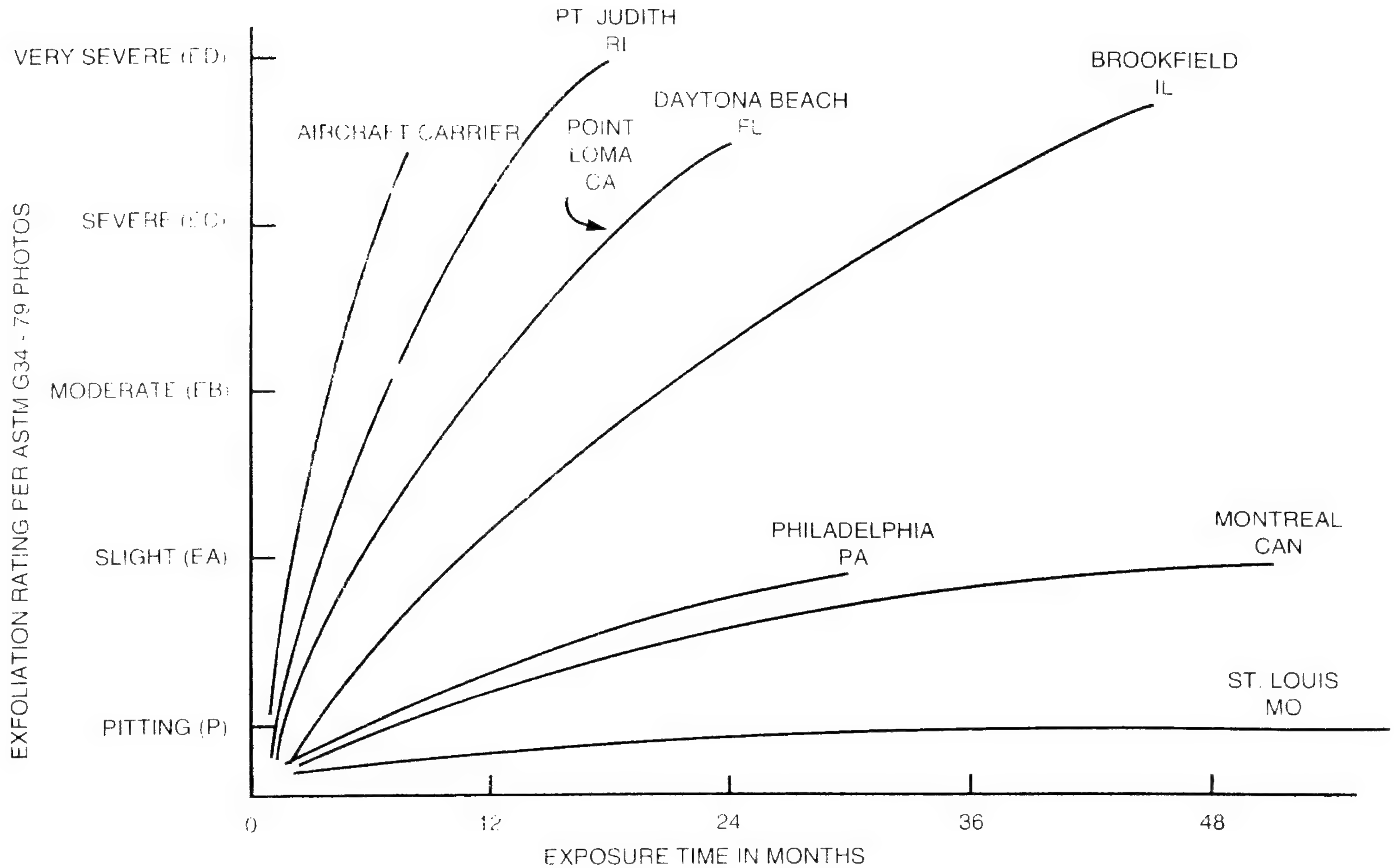


Fig. 1 - *Comparative corrosivity of natural environments*

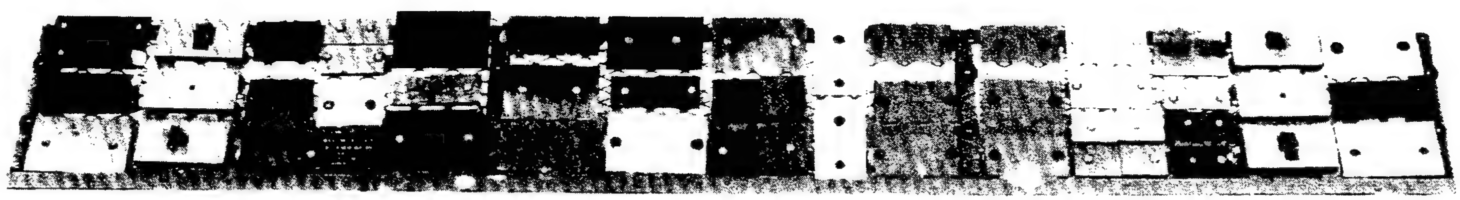
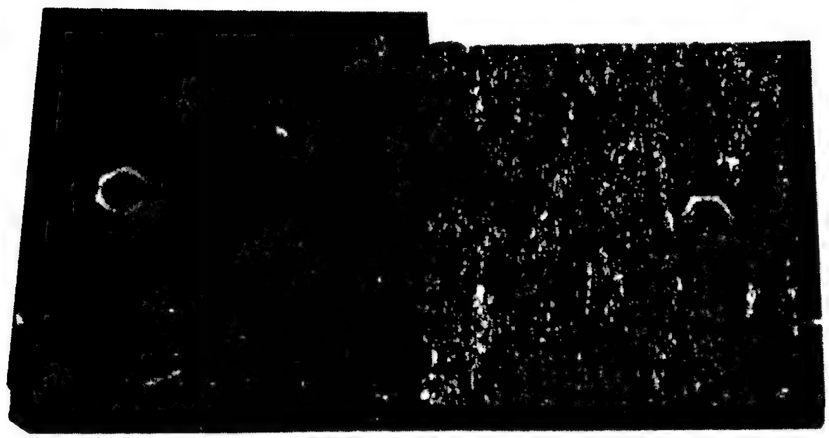


Fig. 2 - Photograph of a typical rack prior to deployment showing the Nylon Fasteners and their Protective Seal.

7075-T651



(a) Exfoliation on T/2 Plane

7075-T7651

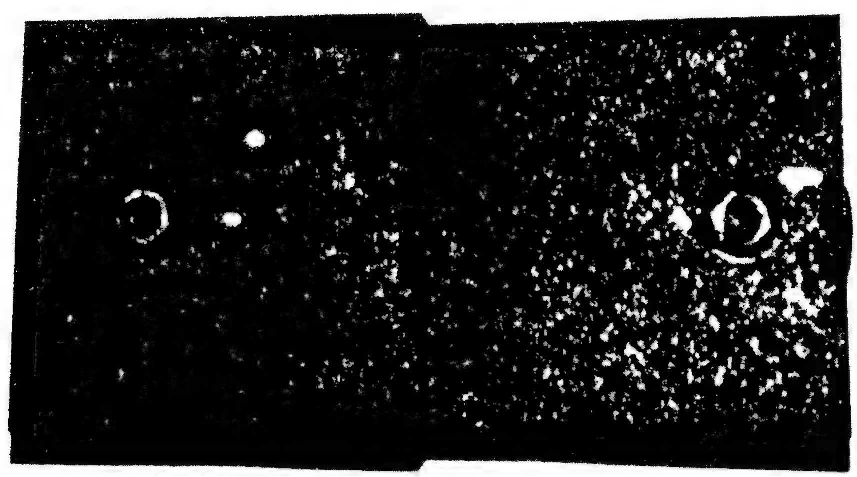
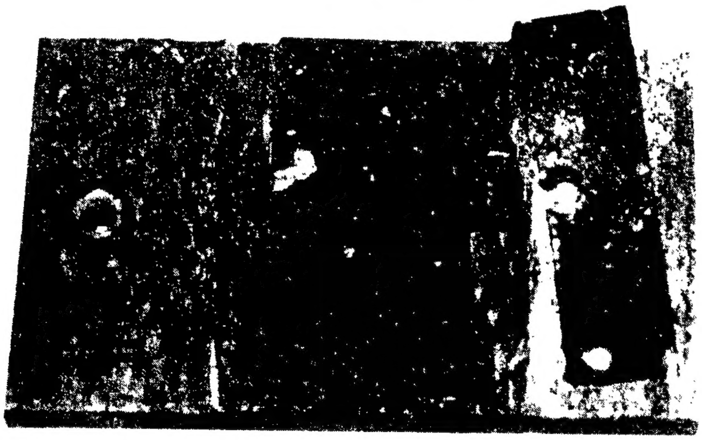


Fig. 3 - Photograph of a step specimen consisting of 7075 - T6 and T 7 after multiple deployments.

7150-T651



(a) Exfoliation

2090-T8E41
0.5 IN

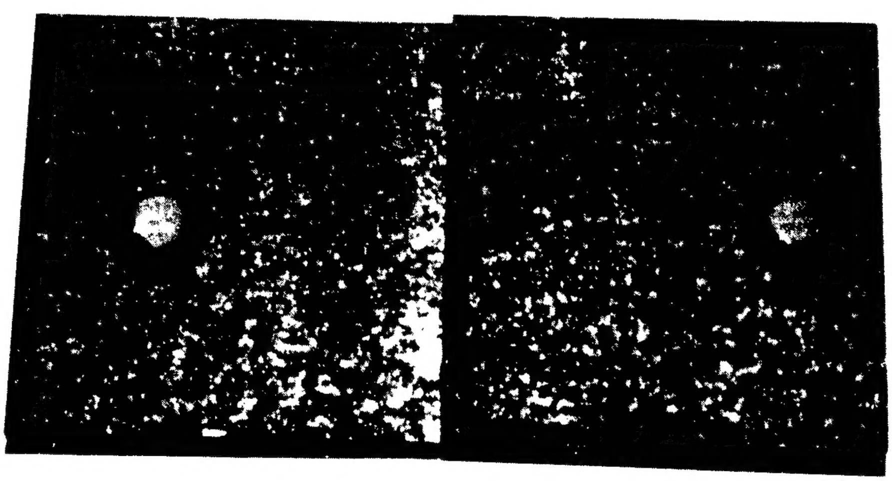


Fig. 4 - Photograph of step specimens 7150 - T6 and 2090 - T8 after multiple deployments.

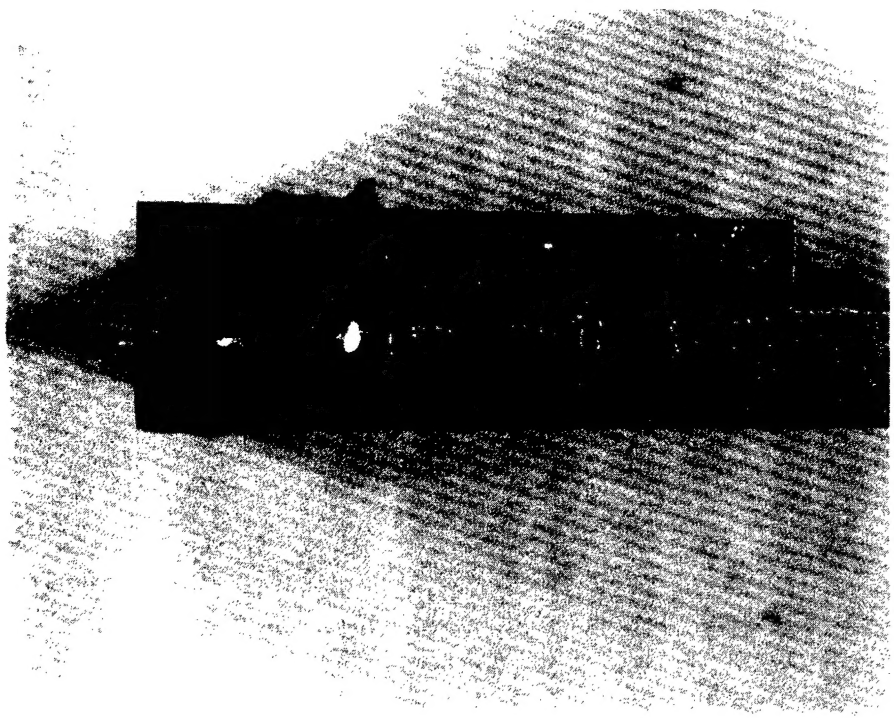
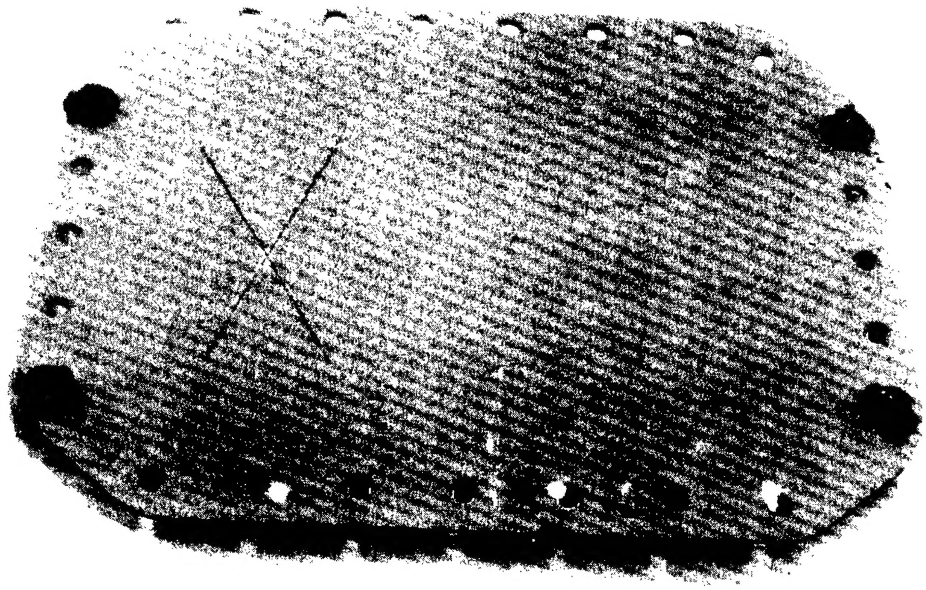
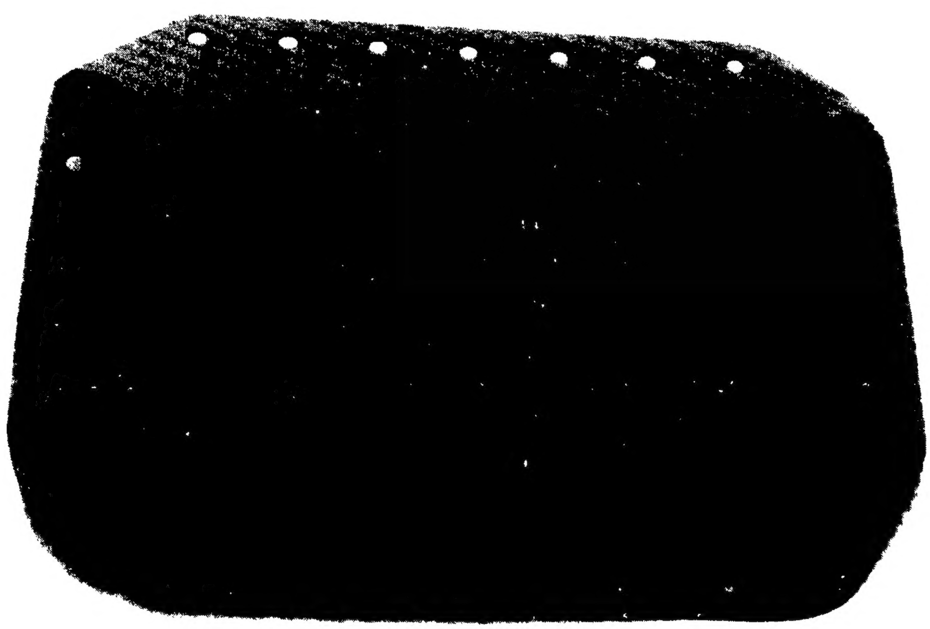


Fig. 5 - Side view of 7075 - 76 alloy showing extensive Ex/ liation.

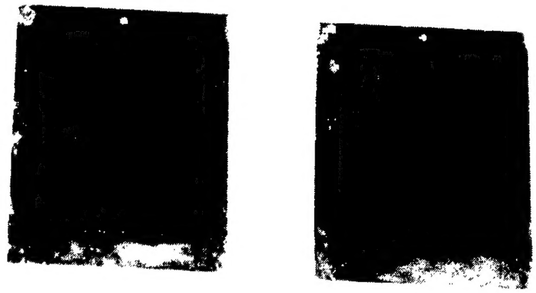


7075 T6
(a)

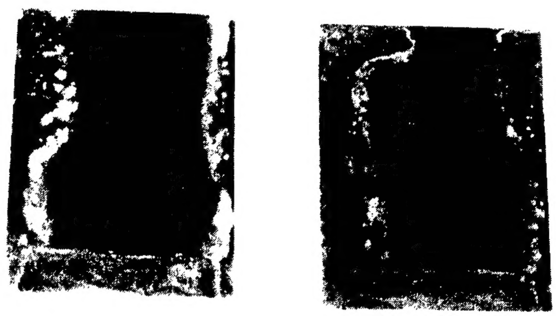


2090 T8
(b)

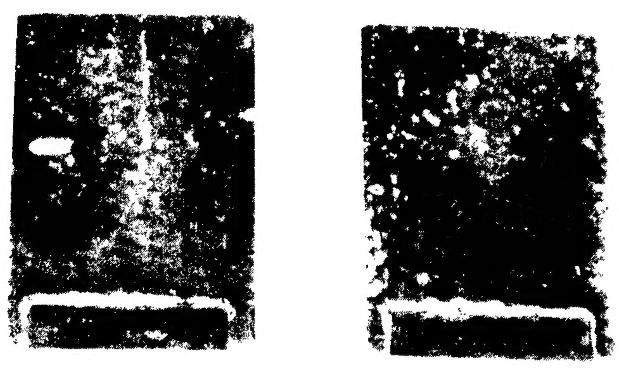
Fig. 6 - Access Panel from F/A - 18 with Scribe Marks.



0.3 mil Cd Plate



0.5 mil Cd Plate



1.0 mil Cd Plate

Fig. 7- Cadmium Plated Steel Panels after 120 hrs of laboratory SO_2 Salt Spray.